Implications of fine-scale magnetics for the structure and evolution of slowly accreted oceanic crust.

Grant No. N00014-94-1-0467
Final Report

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Long-Term Goals:

The long range objective of this program is to understand the structure of oceanic crust created at slow-spreading ridges by investigating the patterns of magnetization that reside in the crust. The project seeks to investigate how crustal magnetic fields are related to the structural deformation history of oceanic crust formed in slow spreading environments and how magnetization may be used to predict the properties of the underlying crust.

Scientific Objectives:

1/ Investigate the relationship between crustal magnetization and the tectonic structure and architecture of oceanic crust by comparing the magnetization patterns of crust created at "inside corners" versus "outside corners" of ridge segment offsets.
2/ Investigate the relationship between crustal magnetization and cyclic magmatic and tectonic processes involved in crustal formation and how this magnetization signal varies with age.
3/ Investigate along-axis variability in crustal magnetization within a ridge segment and compare with the ridge axis signal.
4/ Map magnetic isochrons to provide temporal framework for other related studies e.g. investigate how crustal structure and seafloor morphology change with spreading rate.

Background:

The magnetic data used in this study were collected as part of the ONR Acoustic Reverberation Special Research Project (ARSRP) conducted in 1992 and 1993 on the western flank of the Mid-Atlantic Ridge (MAR) between 25°30 N and 27°30 N and 44°W and 49°W. The primary goal of the ONR ARSRP project is to understand the source and nature of acoustic reverberation at the seafloor. As part of this effort, the seafloor was mapped at a range of scales by several geophysical techniques. The geological/geophysical data from these surveys not only form a regional framework for the ARSRP acoustic studies, but also provide detailed geologic and sub-bottom information on specific sites selected for detailed acoustic experiments. In 1992, sea

surface surveys utilizing swath bathymetry, sidescan sonar, single-channel seismics, magnetics and gravity were obtained in a 200 km wide corridor from the MAR axis at 26°N, westward to approximately 30 My in age (magnetic anomaly 12). In 1993, site specific surveys at four sites were completed using AMS-120 deep-towed sidescan with a fluxgate magnetometer, JASON ROV imaging and dredging. This massive data collection effort provides a unique opportunity to integrate a large number of high quality observations into an overall picture of oceanic crustal structure and evolution in a slow-spreading environment. Crustal magnetism forms an integral part of the geophysical observations and provides a number of important insights and constraints into oceanic crustal formation, structure and evolution.

Accomplishments and Results:

The ARSRP magnetic data were merged with 1) the Mid-Atlantic Ridge North of Kane (MARNOK) data set [Purdy et al.1990] collected in 1989/1990 over the axis of the MAR from the Kane to Atlantis fracture zones and 2) magnetic field data from a larger, coarsely gridded (5 min values) database provided by Dr. J. Verhoef of the Canadian Bedford Institute of Oceanography. Magnetic field data were then inverted for crustal magnetization using the three-dimensional inversion approach of Parker and Huestis [1974], which removes the effect of topography from the magnetic field and automatically corrects for the three-dimensionality of the topography. The primary conclusions of this study are summarized below.

1/ Recent studies of crustal accretion and evolution at the slow spreading MAR have found that accretion at ridge segments creates systematically asymmetric crustal structure. Inside corner crust formed in the zone between the spreading axis and the active offset is primarily composed of lower crustal rocks with the extrusive layer stripped away while outside corner crust, bounded by the spreading axis and the inactive trace of the offset, retains a relatively intact extrusive sequence. This crustal architecture could have an important influence upon the resultant magnetic signal. From this study it is found that crustal magnetization off-axis shows no obvious correlation with tectonic provenance. For each isochron, ridge segments were divided into thirds and then binned according to tectonic provenance (i.e. inside or outside corner or no offset). These bins were then assessed according to their magnetization and no systematic difference in crustal magnetization was found between inside and outside corner crust. This implies that crustal magnetization off-axis is not sensitive to crustal architecture and perhaps more surprisingly that the presence or absence of extrusive crust is not important to the magnetic anomaly signal in these areas. The implication of this result is that the magnetic signal must thus reside within the entire crustal sequence which includes the gabbros, at least for crust created at slow spreading ridges such as the MAR.

2/ Isochronal trends in off-axis crustal magnetization were investigated and it was found that while normally magnetized crust shows little or no variation along an isochron within a ridge segment, reversely magnetized crust consistently shows significantly more positive magnetization towards segment discontinuities than at segment centers. This trend is attributed to the preferential destruction of original remanence at segment ends and the substitution of either a viscous or induced magnetization. Such magnetization is always positive in the present day field. These observations along with the finding that the presence or absence of extrusive crust has little

effect upon the magnetic signal suggests that the source of this additional magnetization presumably lies within the gabbro or peridotite sequence. Further studies are needed of the magnetization of oceanic gabbros and upper mantle rocks to test these speculations. Induced or viscous magnetization also tend to enhance the linearity of magnetic anomalies, if the ridge-axis and crust is subparallel to the magnetic meridian, as it is with the MAR and most of he world's midocean spreading centers.

3/ Sea surface magnetic data suggest that crustal magnetization decays in amplitude with age over a 10 m.y. period although this is probably an underestimate of the swiftness of the decay rate because of the intrinsic poor resolution of sea surface data. Decay may occur on a significantly faster time scale. Simple crustal emplacement models of slowly accreted crust can produce an apparent decay in magnetization due to the overlapping of polarity sequences. The filtering effect of the crustal accretion process linked with the filtering due to water depth means that sea surface studies should be used with caution in determining magnetization decay rates. A better estimate of decay rate can be obtained with deep tow magnetic surveys which will have a factor of 10 improvement in resolution in slow-spreading environments.

4/ All major isochrons were identified and digitized from the magnetization inversion map for the entire ARSRP study region. Isochrons provide the basic temporal framework for plate motion studies and ridge segment evolution. The average spreading half-rate for the western MAR from 0 to 30 Ma has decreased from about 17 mm/yr. to 10 mm/yr. at present. Migration rates for the growth and decline of individual ridge segments appears to occur at rates of about 2.6 mm/yr.

Publications

Kleinrock, M.C., B.E. Tucholke, J. Lin, and M.A. Tivey, The trace of nontransform offsets and the evolution of Mid-Atlantic Ridge spreading segments between 25°25'N and 27°10'N over the past 30 m.y., *EOS Trans. AGU, 73*, 43, 538, 1992.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
2 January 1997

3. REPORT TYPE AND DATES COVERED
Final, 1 Feb. 94-31 May 96

4. TITLE AND SUBTITLE
Implications of fine scale magnetics for the structure and evolution of slowly accreted oceanic crust

5. FUNDING NUMBERS
G: N00014-94-1-0467

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER
13046700

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
Ballston Towers One/800 N. Quincy St.
Arlington, VA 22217-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A detailed sea surface magnetic survey of the west flank of the Mid-Atlantic Ridge (MAR) between 0 and 29 m.y. encompasses several ridge segments and documents the history and evolution of crustal magnetization of slowly accreted crust. Crustal magnetization shows no difference between inside and outside corner crust indicating that the off-axis magnetic signal is not sensitive to crustal architecture or lithology. Isochronal trends in off-axis crustal magnetization find that normally magnetized crust shows no variation along-isochron, while reversely magnetized crust shows significantly more positive magnetization towards segment discontinuities. We attribute this trend to the preferential destruction of original remanence at segment ends and the substitution by either viscous or induced magnetization. These observations along with the finding that the presence or absence of extrusive crust has little effect upon the magnetic signal suggests that the source of this additional magnetization presumably lies within the gabbros or mantle. Finally, magnetization decays with age over the first 10 m.y. but the aliasing created by the crustal accretion process at slow spreading rates, and the filtering of water depth produces an apparent rapid decay over the first 5 m.y. Only near-bottom surveys with increased resolution are able to detect such decay trends.

14. SUBJECT TERMS
Marine magnetism, Mid-Atlantic Ridge

15. NUMBER OF PAGES
3

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102